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Experimental Study on Vehicle Integration of a Compound Regeneration System for Diesel Particulate Filter

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Abstract

A compound regeneration system has shown potential in DPF regeneration. The system consists of FBC, burner and DOC to adapt to high sulfur in China. An aging test of 60,000 km and environmental compatibility test in cold zone, tropical zone and plateau is carried out, with the system integrated on Foton BJ1049V9JD6-SB light duty diesel. Statistics show aging of DPF promotes filtration efficiency because of microstructure change. Both DOC and engine aging are important elements of HC and CO increase. The working effect in cold zone and tropical zone and adaptability of regeneration device in plateau are discussed. The results reflect strong adaptability of regeneration device and discover the main difficulty for system application, which refers to overproof emissions due to aged DOC.

Key words-diesel particulate filter; compound regeneration; vehicle integration; experienental study

1. Introduction

Diesel Particulate Filter (DPF) is acknowledged as the most effective purification technique for particulate matter. The most representative filter material for diesel particulate filter is the wall-flow filter developed by Corning[1]. The wall-flow filter has solved the contradiction between filter efficiency and pressure drop, resulting in filter efficiency to 90% and low pressure drop. It is examined that the pressure drop during working period is 1 to 15kPa. Common used filter materials include cordierites, SiC and a new aluminum titanate ($Al_2O_3 \cdot TiO_2$). The new aluminum titanate appeared in the market in 2006, and shows strong durability in regeneration test [2].

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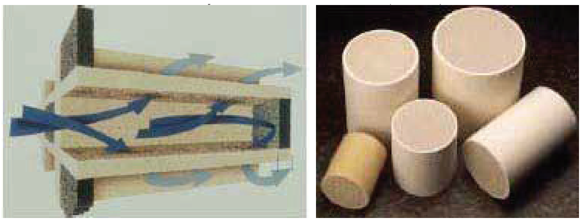


Figure 1. Working principle and appearance of wall-flow diesel particulate filter[3]

The regeneration technology is always a difficulty in domestic DPF study. The regeneration of DPF refers to removing the PM in DPF so that the filter efficiency can be recovered. The regeneration of filters can be divided to passive regeneration and active regeneration [4]. The active regeneration refers to regeneration that heats the internal temperature of DPF to burn PM with the help of external energy. The passive regeneration refers to regeneration that uses the energy from exhaust of diesel engine. In order to realize passive regeneration, catalysts are commonly used to decrease burning temperature of PM.

Fig. 2 shows the changes of exhaust temperature from 4JB1 diesel engine in I type test of National standard III. We can see that the exhaust temperature from light duty engine is primarily below 300℃ on city road, while the burning temperature of PM is commonly above 600℃.

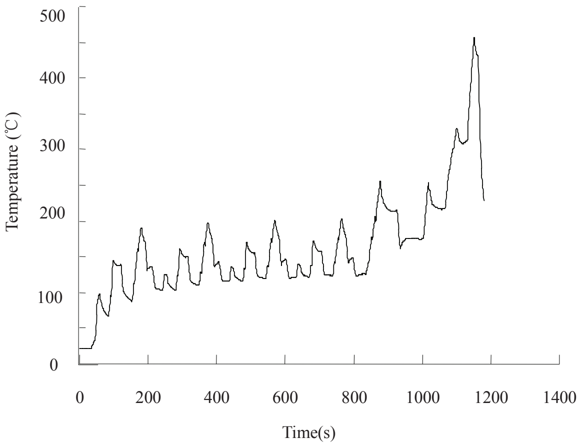


Figure 2. The changes of exhaust temperature from engine in I type test of National standard III.

Diesel Oxidation Catalyst (DOC) and Continuously Regenerating Technology (CRT) is widely accepted in European and U.S. markets, but for their high dependence on catalyst, it has poor adaptability to high sulfur. In most provinces of China, sulfur content of diesel fuel is up to 300ppm, which is lethal to catalyst. Consequently, it's necessary for China to develop a countermeasure to high sulfur [5] [6].

In order to realize the regeneration of PM effectively, the paper has designed a compound regeneration system with cordierites as filter materials. The regeneration is realized by reducing the burning temperature of PM by use of FBC and increasing exhaust temperature by use of burner and DOC.

3. System schema

The device decreases emission of NOx by EGR; reduces emission of HC and CO by DOC; filters PM by DPF. Please refer to total design of the system in Fig. 3.

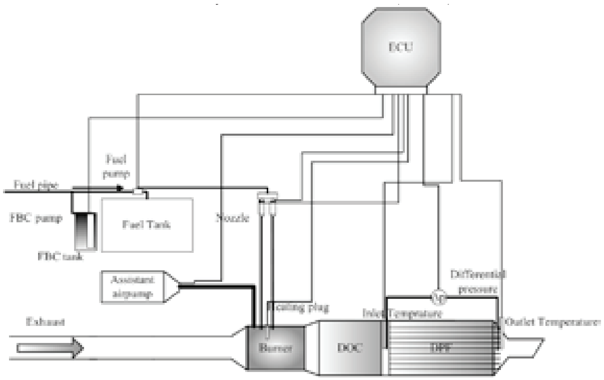


Figure 3. System Structure of DPF.

The working of system: reads the changes of liquid level in fuel tank; calculates fuel charge and corresponding amount of FBC; inputs the FBC into oil return pipe flowing to fuel tank after refuel; catalysts generated from the burning fuel with FBC attaches on PM and flow with exhaust to be collected by DPF; the system regenerate DPF when determines the accumulation of PM is above certain level; with the instruction of regeneration, the burner will heat the exhaust to certain temperature after lighting and burning, and then exhaust temperature rises again after DOC oxidizes HC and CO, resulting in regeneration of DPF. Please refer to table 1 for main parameters of DPF system.

Table I. Main Parameters of DPF System.

Items	Parameters
Type of additives	Infieum F7991
Proportion of addition（V/V）	0.241：1000
Filter material	cordierites
With/ without catalysts coated	without
Volume of filter /L	5.668
Bean size of filter	200

4. Testing organization

Please refer to table 2 for main parameters of testing vehicle. Fig. 4 shows the appearance of vehicle and system integration method of DPF in vehicle.

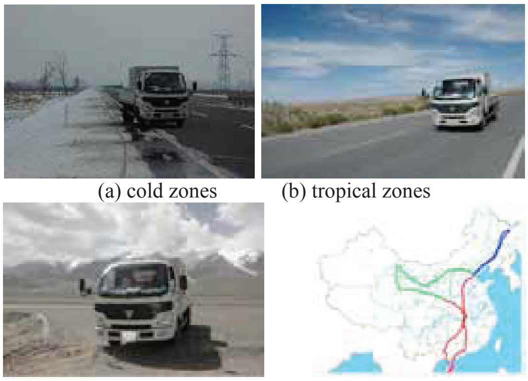
In order to verify the working feature of system in different environments, the vehicle verification tests are carried out in cold zone, tropical zone and plateau. The cold zones include Shenyang in Liaoning Province and Qiqihaer in Heilongjiang Province. The tropical zones include Sanya in Hainan Province. The plateaus include Golmud in Qinghai Province and Dunhuang in Gansu Province. Fig. 5 is a collection on the route.

Table II. Main Parameters of Testing Vehicle.

Items	Parameters

Items	Parameters
Type of vehicle	BJ1049V9JD6-SB
Type of engine	BJ493ZLQ3
Curb weight /kg	2500
Nominal load /kg	1860
Output volume/L	2.771
Emission level	National standard III

Figure 4. Testing Vehicle and Vehicle Integration of DPF System.



(a) cold zones (b) tropical zones

(c) plateaus zones (d) route chart

Figure 5. Vehicle Tests in Different Geographical Regions.

5. Analysis of test results.

5.1 Aging Feature of DPF

Fig. 6 shows the changes of PM emission from vehicle within 60,000km.We can see that the emission of PM is much lower than emission from new DPF after the vehicle runs 60,000km. It directly connects with the filter microstructure of DPF. The accumulation of ash from fuel and FBC will lead to the block in internal pore canal of filter, resulting in the smaller gap in the wall of filter and high filtration efficiency of PM [7]. It is must be made clear that the data is collected after regeneration of DPF. The DPF will show different filtration efficiency in different PM loads: with the accumulation of PM, the filtration efficiency increases [8].

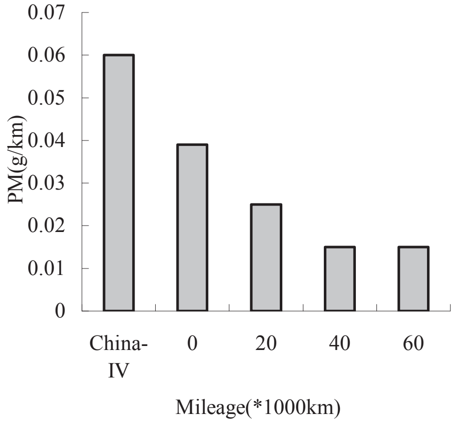


Figure 6. Changes of PM Emission

5.2 Aging Feature of DOC

The functions of DOC are in two aspects: 1. increase the exhaust temperature; 2. oxidize the CO and HC in the exhaust. Please refer to Fig. 7 and Fig.8 for the changes of CO and HC in exhaust. The measured CO is about 22% of national standard IV after the integration of devices, 0.529g/km after 20000km, and 0.909g/km after 40000km, which have exceeded the emission limit of national standard IV. The national standard IV has not defined the emission of HC, but has defined the emission of NOx(0.39g/km) and Nox+HC(0.46g/km) respectively. As a result, we can use 0.07g/km as a standard that meet with the purification standard of HC. The emission of HC increases from 0.039g/km to 0.045g/km from 0 to 40000km, which reflects an unobvious change. However, the emission of HC increases to 0.077g/km in 60000km which may transfinite NOx+HC [9].

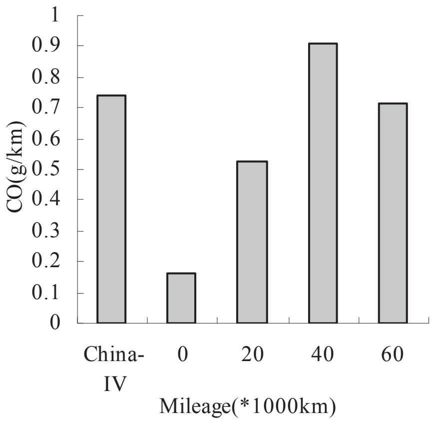


Figure 7. Changes of CO Emission

It can be found from the above data that there is an obvious aging situation in DOC during the tests, mainly appearing as the increase emission of HC and CO. The emission of CO exceeds standard in 40000km, and the emission of HC caused the transfinite of NOx+HC in 60000km. The aging DOC is caused by sulfate in PM.

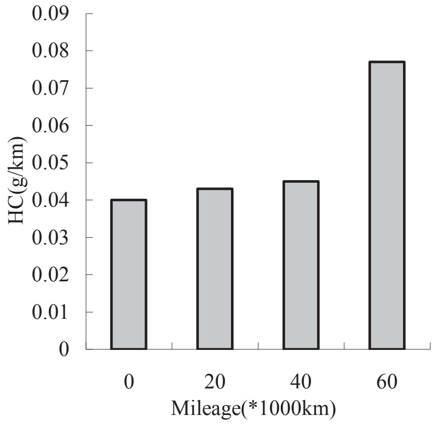


Figure 8. Changes of HC Emission

However, besides the sulfur poisoning, the emission deterioration of diesel engine also leads to emission increase. In order to determine the aging level of DOC, we have carried out contrast test in 60000km: carried out emission test in the testing vehicle with aged DOC and new DOC. The result is in figure 8.

We can see that from the process that the emission of CO increases from 0.16g/km to 0.712g/km, the increased emission caused by aged engine is 0.235g/km, and the increased emission caused by aged DOC is 0.307g/m, which accounts from 43% and 57% respectively. During the process that the emission of HC increases from 0.039g/km to 0.077g/km, the increased emission caused by aged engine is 0.008g/km, and the increased emission caused by aged DOC is 0.03g/m, which accounts from 21% and 79% respectively.

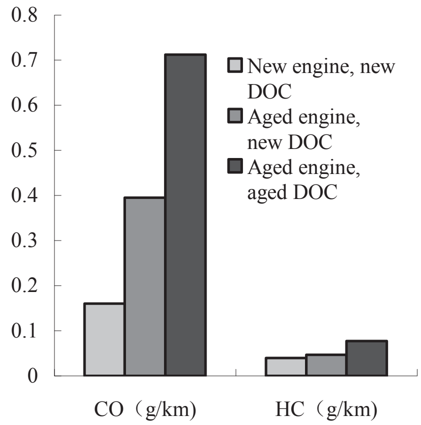


Figure 9. Influences of Aged Engine and aged DOC on Emission of CO and HC

5.3 Environmental thermal adaptability

The regeneration temperature curves of cold zones and tropical zones are shown in Fig.10 and Fig.11. The environmental temperature of cold zones is about -20℃, and the environmental temperature of tropical zones is about 35℃.

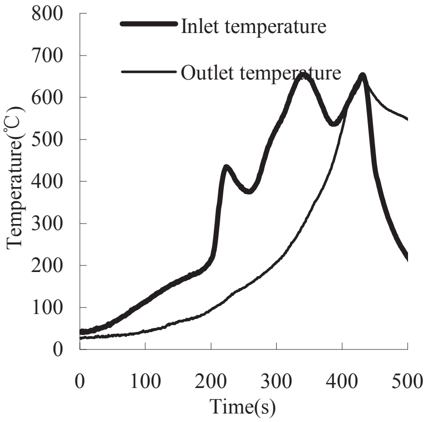


Figure 10. Typical Regeneration Temperature Curves in Cold Zones (Environmental Temperature: -20℃)

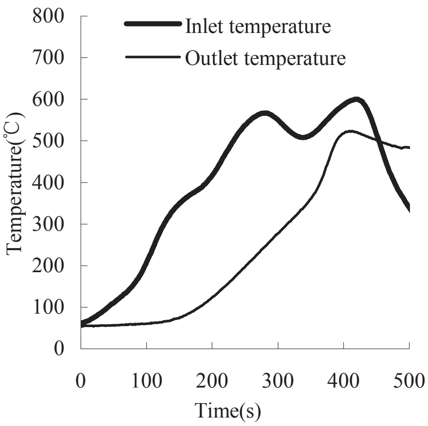


Figure 11. Typical Regeneration Temperature Curves in Tropical Zones (Environmental Temperature: 35℃)

It can be seen from Fig. 10 that the temperature rises slowly during the ignition period of burner in cold zones, mainly due to oil supply and heat loss. The ignition of the second grade oil supply is in 210 seconds, but the temperature drops a certain level after oil supply due to the difficult ignition of second grade. After the success ignition of second grade, the temperature rises rapidly, and the inlet temperature of DPF increases to 600℃ within 320 seconds, and the outlet temperature of DPF increases to 600℃ within 400 seconds. It can be seen from Fig. 11 that the temperature rises rapidly during the ignition period for the temperature increases to about 600℃ within 280 seconds, and the temperature behind the

DPF increases to the max within 380 seconds. The temperature PID control shall be carried out to maintain the inlet temperature after the inlet temperature of DPF reaches 550℃.

It can be found through analysis that the burner system has good adaptability to temperature. The problems include difficult ignition in cold zones resulting in increased oil consumption and decreased reliability of ignition.

5.4 Plateau environmental adaptation

The figure 10 shows regeneration temperature curve in Golmud. It takes only 240 seconds for inlet temperature of DPF to increase to 600℃ from ignition, and the outlet temperature of DPF reaches to the max in 260 seconds. The temperature rises steadily and rapidly. The difference between the inlet temperature and outlet temperature of DPF is small.

The reasons for the above situation may include: 1. the concentration of oxygen. The burning speed of gas mixture reaches the max when the concentration of oxygen is rich. As the control strategy for burner is not adjusted in plateau, so the gas mixture must be with high concentration resulting in quicker heating speed; 2. The flow rate of exhaust in engine decreases. In the same working conditions, the decreases flow rate of air inflow will lead to the decreased flow rate of exhaust in the engine which will decrease the heat loss of exhaust during the heating process and accelerate the warming up of DPF.

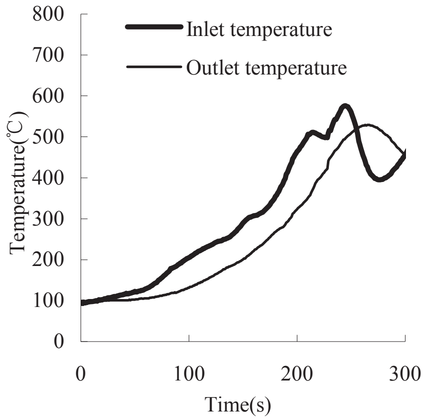


Figure 12. Typical Regeneration Temperature Curves in Plateau

5. Conclusion

The following conclusions come out after the integration and test of the system

1) The filtration efficiency of DPF increases rather than decreases along with the travel distance. It is mainly because the accumulation of ash decreases the gap in the wall of filter.
2) With the increasing travel distance, the DOC aging and emission deterioration of engine may cause the transfinite emission of CO and exorbitant emission of HC, resulting in the transfinite emission of NOx+HC. The DOC aging plays a leading role in the emission.
3) With the difficulty during the ignition of burner in the cold zone, reliability and fuel economy of the system may be influenced.

4) In plateau, with the help of subsidiary air pump, the burner works smoothly with burning performance better than in flatlands.

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References

[1]HE Hong, WENG Duan and ZI Xin-yun, "Diesel Emission Control Technologies: A Review", Environmental Science, Vol. 28, No. 6, Jun., 2007 pp. 1169-1177.

[2]Timothy V. Johnson. "Diesel Emission Control in Review", SAE Paper, 2007- 01-0233, 2007.

[3]Mansour Masoudi, Achim Heibel. "Predicting Pressure Drop of Wall-Flow Diesel Particulate Filters--Theory and Experiment", SAE Paper, 2000-01-0184, 2000.

[4]Ministry of Environment Protection, P.R.C. "HJ 451-2008. Technological Standard for Environmental Protection Device: After-treatment Device for Diesel Emission", 2008:2.

[5]Yasuharu Kanno, Yasushi Tanaka, Yasuyuki Banno, Makoto Nagata. "Study of DOC+CSF Optimization", SAE Paper, 2006-01-3285.

[6]Ronny Allansson, Philip G. Blakeman, Barry J. Cooper, Howard Hess,Peter J. Silcock, Andrew P Walker. "Optimizing the Low Temperature Performance and Regeneration Efficiency of the Continuously Regenerating Diesel Particulate Filter (CR-DPF) System", SAE Paper, 2002-01-0428.

[7]Athanasios G. Konstandopoulos, Margaritis Kostoglou, Evangelos Skaperdas, Eleni Papaioannou, Dimitrios Zarvalis and Evdoxia Klado. "Fundamental Studies of Diesel Particulate Filters: Transient Loading, Regeneration and Aging", SAE Paper, 2000-01-1016.

[8]Tinghong Tao, Willard A. Cutler, Kenneth Voss and Qiang Wei. "New Catalyzed Cordierite Diesel Particulate Filters for Heavy Duty Engine Applications", SAE Paper, 2003-01-3166.

[9]T. Nakane, M. Ikeda， M. Hori，O. Bailey， L. Mussmann. "Investigation of the Aging Behavior of Oxidation Catalysts Developed for Active DPF Regeneration Systems", SAE Paper, 2005-01-1759.